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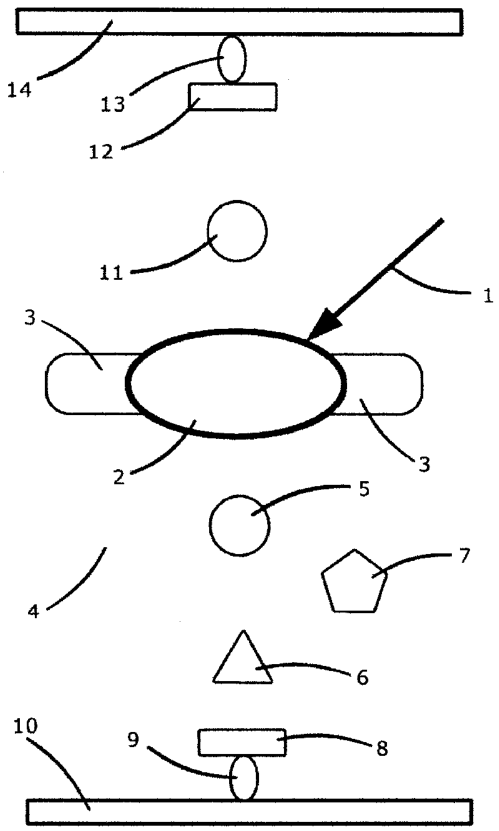
(56) Documents Cited:
WO 2006/060017 A1 **JP 040270926 A**
US 6231983 B1 **US 20050098726 A1**
US 20050041458 A1
Lam K. B. et al, "A bio-solar cell powered by sub-cellular plant photosystems", 17th IEEE International Conference on Micro Electro Mechanical Systems, pp220 223 (2004)

(continued on next page)

(54) Abstract Title**: Solar cell using photosynthesis**

(57) A method of utilising some of the molecular components involved in the process of photosynthesis to generate electrical potential from incident light is disclosed. A number of molecular photosynthetic molecules 2 are used to absorb light energy, produce energised electrons and to transfer these electrons by a cascade of electron transfer molecules 5, 6, 8 to an electrode 10. The molecular components 2 are contained in a vessel (19, fig 2) that allows light to enter and the electrodes 10, 14 are positioned to allow electricity generated by the device to be transferred to external circuitry. The device specifically uses a photosystem I (PS I) complex as the active medium of a photovoltaic device.

Figure 1



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The claims were filed later than the filing date but within the period prescribed by Rule 25(1) of the Patents Rules 1995.

(56) cont
Lee I et al., "Biomolecular electronic devices with photosystem I reaction centers", 57th Annual Device Research Conference Digest, pp62-63 (1999)
Cogdell R. J. and Lindsay J. G., "Can photosynthesis provide a 'biological blueprint' for the design of novel solar cells?", Trends in Biotechnology, vol. 16, pp521-527 (1998)
Das R et al., "Integration of photosynthetic protein molecular complexes in solid-state electronic devices", Nano Letters, vol. 4, pp1079-1083 (2004)

(58) Field of Search:
INT CL **H01L**
Other: **EPODOC, WPI, INSPEC, TDB, XPAIP, XPESP, XPI3E, XPIEE, XPIOP, INTERNET**

Figure 1

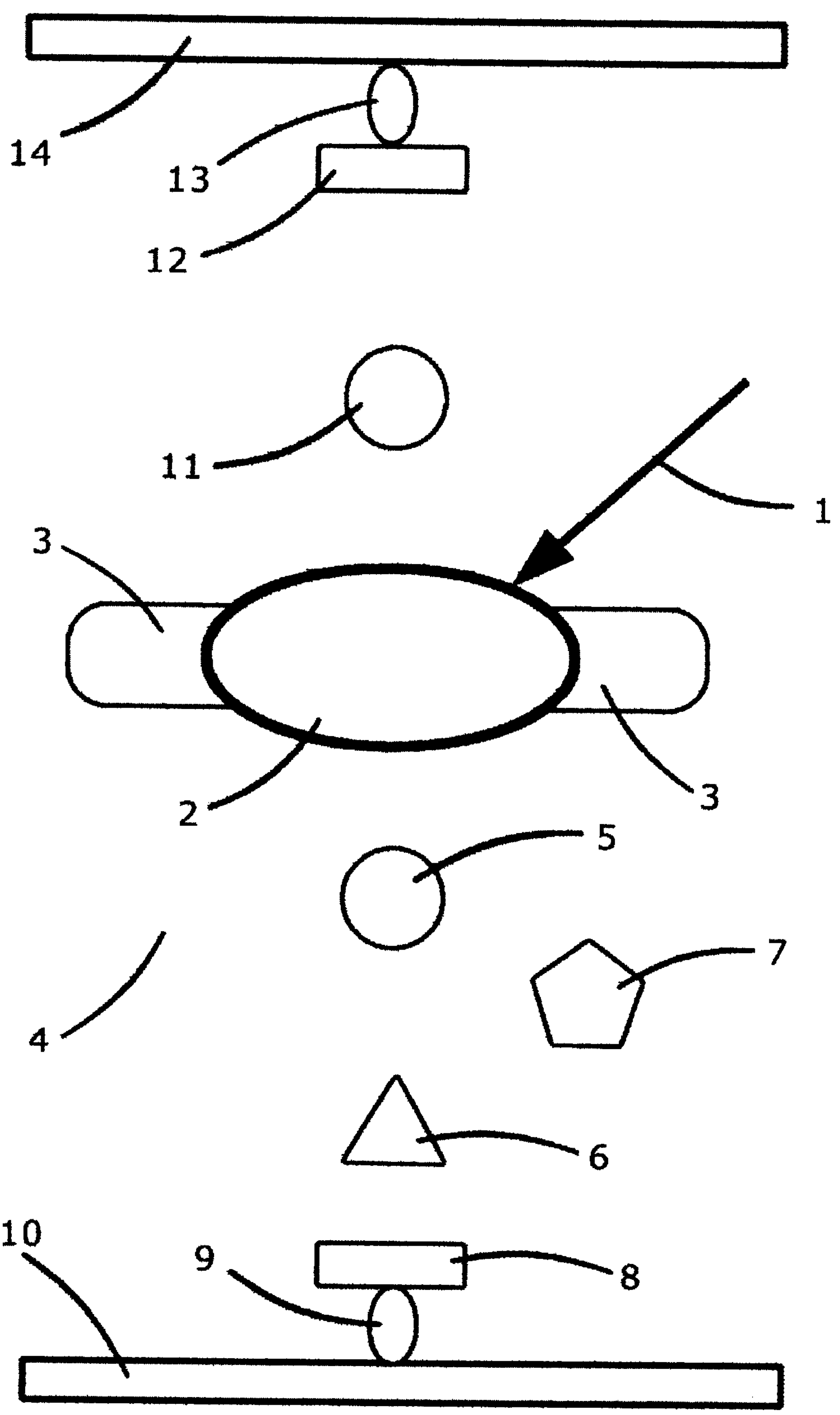


Figure 2

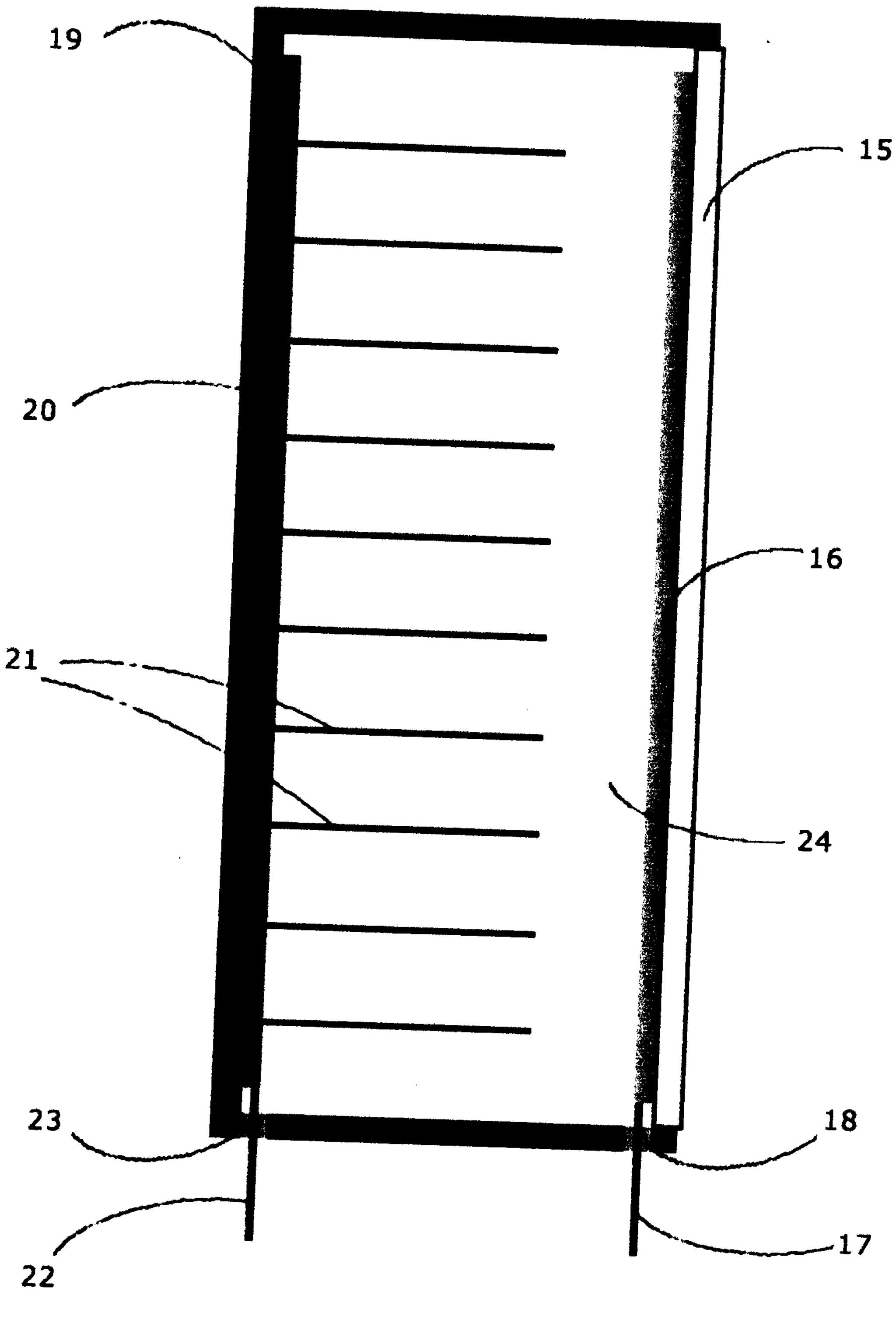
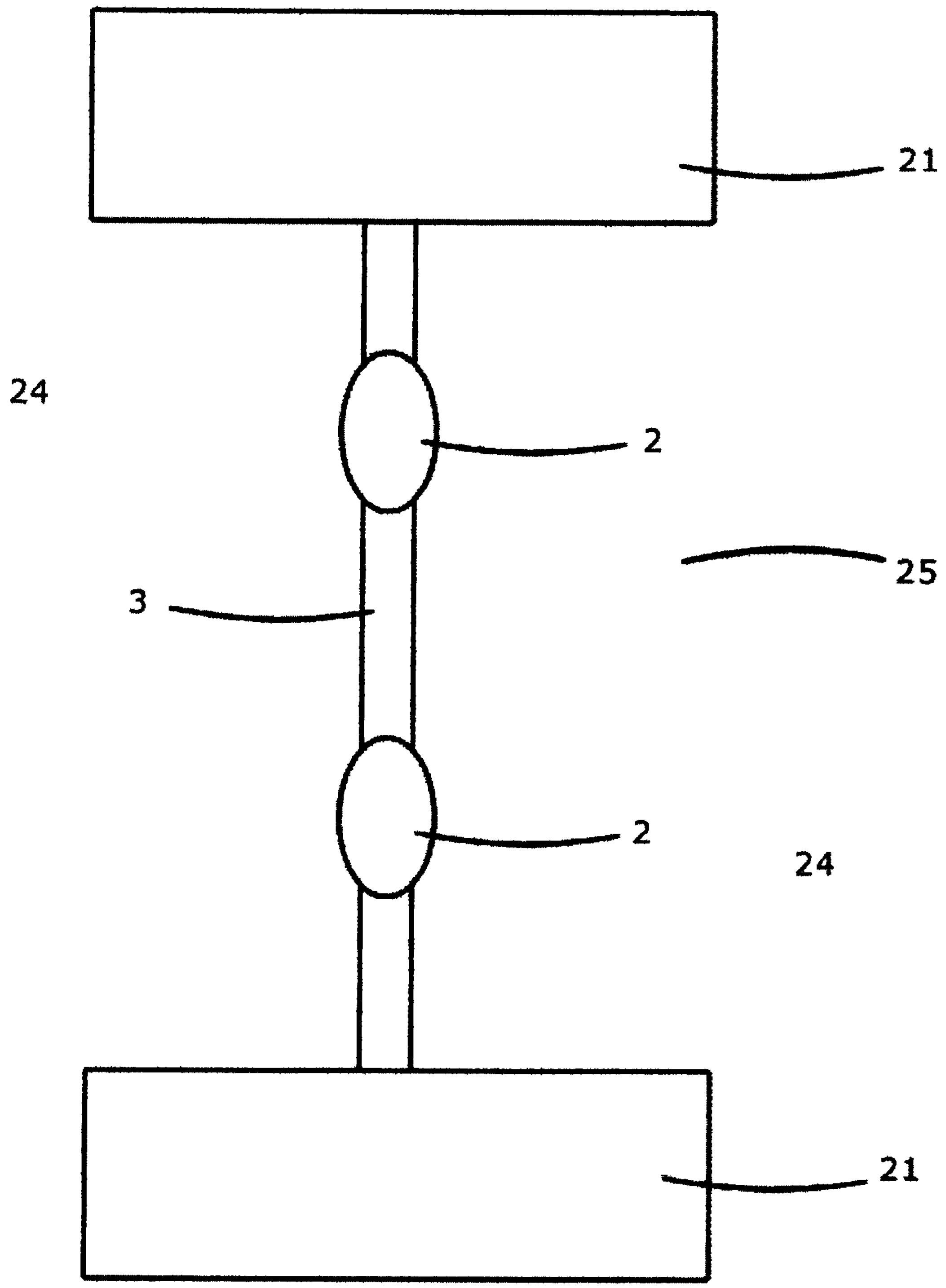


Figure 3



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TITLE

A method of generating electricity.

BACKGROUND

This patent relates to the field of solar photovoltaic electricity generation.

Alternative means to generate electricity are becoming desirable due to various factors including, but not limited to: rapidly increasing energy demands across the world, the depletion of commonly used hydrocarbon fuels, the desire to reduce various types of pollution, and the increased awareness of the climatic consequences arising from large-scale fossil fuel usage. A number of alternative energy technologies are currently in use and being further developed, including: wind power; wave and tidal power; biomass; and solar (both thermal and photovoltaic).

Brief consideration of the quantity of solar energy that reaches the Earth's surface annually is sufficient to illustrate the significant potential of this as an energy source. Approximately 3×10^{24} J of energy from the Sun reaches the Earth's surface every year. Of this, about 50% is in the photosynthetically active region of the electromagnetic spectrum i.e. 400nm to 700nm, the visible light region. To put this quantity of energy in perspective, the human race only uses approximately 4×10^{20} J of energy per year, including biomass.

Photovoltaic devices that are currently available on the market, based on silicon semiconductor technology, have peak sensitivities around 830nm and only convert light into electricity with efficiencies up to around 17%, even under ideal conditions. Workers over the past few decades have attempted to construct different means of converting light into electrical energy and to improve current technologies, such as: dye sensitized solar cells (US 7019209), nanocrystalline titanium dioxide layer solar cells (US 6245988), linear chromophore arrays (US 6596935) and improved thin-film solar cells (US 7019207). However, there still remains a need for higher efficiency solar cells, especially those that more strongly absorb the shorter wavelengths of light.

Photosynthesizing plants, algae and certain bacteria can use incident solar energy to produce various forms of chemical energy. Some photosynthesizing organisms are also capable of using low light conditions, which current solar PV technology poorly exploits. The process of photosynthesis at the molecular level has a key step that involves the absorbance of light energy and the production of energised electrons. These electrons are used later to construct molecules that are useful to the organism. This present invention utilises this key step and parts of the photosynthetic molecular machinery to generate electricity.

The present invention provides means to absorb incident light and to convert this energy into an output in the form of electrical energy. To this end this patent describes the use of parts of the photosynthetic molecular apparatus of a variety of organisms, for example green plants, to perform this conversion. In addition, means of supplying electrons to the above light absorbing apparatus and means of accepting energised electrons from the light absorbing apparatus are also included in the invention. In addition, means of connecting the invention into some external electrical circuit are also included.

Some of the objects and advantages of the present invention are to better utilise the energy-dense visible light region of the spectrum and also to convert such light energy into electricity with considerably higher efficiency than photovoltaic cells currently available on the market.

Preferably the invention uses a number of different types of light-absorbing molecular complexes to increase the absorbance at specific wavelengths.

Preferably the invention is sealed within an airtight container having at least one transparent side of large surface area to allow the ingress of light.

Preferably the invention includes means to protect the light-absorbing molecular complexes and other components under a range of environmental conditions.

The invention will now be described via the description of a preferred embodiment with reference to the accompanying drawings:

Figure 1 shows a preferred embodiment at the molecular level.

Figure 2 shows a preferred embodiment incorporated into a solar panel.

Figure 3 shows a detail of the preferred embodiment shown in figure 2.

DESCRIPTION

Figure 1 shows a preferred embodiment of the invention, at the molecular level. The components are represented symbolically for clarity and do not represent true relative sizes or shapes of any molecules concerned. The figure primarily shows a cascade of electron transfers (redox reactions) initiated by light energy. A quantum of light energy 1 enters the device and is absorbed by the light-absorbing molecular complex 2, (in this case the photosystem I and associated light-harvesting complex extracted from a green plant). Molecular complex 2 is embedded in a membrane bilayer 3 (in this case a phospholipid bilayer) such that the hydrophilic faces of molecular complex 2 are exposed to the aqueous solution 4 containing buffers and other components to maintain pH and system stability. The quantum of light 1 energises an electron within the complex 2.

This energised electron is then passed onto an acceptor molecule 5 (in this example ferredoxin). The electron is then passed from acceptor molecule 5 onto acceptor molecule 6 (in this case $NADP^+$), thereby reducing the molecule to NADPH. This reaction requires the enzyme ferredoxin NADP reductase 7 as a catalyst. The electron is then passed from acceptor molecule 6 to a further acceptor molecule 8 (in this example pyrroloquinoline quinone) that is bound by a linker molecule 9, (in this case a cystamine), to the gold anode 10.

Once the energised electron is passed from complex 2 to acceptor molecule 5, an electron is donated to complex 2 by a donor molecule 11, (in this case plastocyanin). The donor molecule 11 in turn accepts an electron from a further donor molecule 12, (in this case cytochrome f), that is bound by a linker molecule 13 (that, in this case, consists of a disulphide group that includes an organic functional unit), to the gold cathode 14.

In the described series of electron transfer reactions (redox reactions) each step proceeds via highly specific molecular interactions. These preclude alternative routes for electron transfer. For instance, in this embodiment, donor molecule 11 (plastocyanin) only donates its electron via a specific binding site found on one face of the light-absorbing molecular complex 2. In turn donor molecule 11 only accepts an electron from donor molecule 12, (in this case cytochrome f) due to the requirement for highly specific binding partners.

Figure 2 shows a preferred embodiment of the invention, as described in figure 1, incorporated into a solar panel. The figure shows a cross section through a solar panel that uses the present invention to generate electricity from sunlight. The cross section is of the order of 1cm across its narrowest dimension, but the drawing is not to scale and merely for illustrative purposes. The upper face of the panel, that is exposed to sunlight, has a transparent casing 15. To the inner side of casing 15 is bound an array of cathode wires 16 such that minimal blockage of light occurs, that is connected to a wire 17 that leads through an airtight seal 18 to the exterior of the device. The base and sides of the device 19 are a casing made of some appropriate material, in this case a plastic, sealed to casing 15 in an airtight manner. Attached to the interior face of the casing 19 is the anode 20. Attached to the anode 20 are numerous thin plastic sheets 21, (the detailed construction of these is shown in figure 3). Anode 20 is connected to a wire 22, that leads through an airtight seal 23 to the exterior of the device. Filling the space between the above components, interior to the device, is the solution 24 containing the aqueous electron transfer components (as detailed in figure 1) and other components such as pH buffers.

Figure 3 shows a preferred embodiment of plastic sheets 21 (see figure 2). Plastic sheets 21 are typically, in this embodiment, of the order of 0.5mm thick, 8mm high (from the anode to the apex, as shown in figure 2) and almost the same length as the particular embodiment of the device, e.g. 30cm long. The components in figure 3 are not drawn to scale. The figure shows a cross section through a small portion of plastic sheet 21. The length of the section shown is of the order of 1mm. The sheet 21 is a mesh having a large number of small holes, with hole 25 being one such, and hole 25 being of the order of 0.5mm in diameter. Stretched across hole 25 is a membrane 3 (in this case a phospholipid bilayer, see figure 1) that has embedded within it a number of light-harvesting complexes 2. Both sides of the hole 25 are bathed in solution 24, that contains the aqueous electron transfer components (as detailed in figure 1) and other components such as pH buffers.

CLAIMS

1. a device that absorbs light energy and converts this into an electrical output.
2. a device according to claim 1 that uses photosynthetic molecules to absorb light energy.
3. a device according to claim 1 that uses photosynthetic molecules to donate electrons.
4. a device according to claim 1 that uses photosynthetic molecules to donate electrons to electron acceptor molecules.
5. a device according to claim 1 that uses photosynthetic molecules to accept electrons from electron donor molecules.
6. a device according to claim 1 that uses photosynthetic molecules to donate electrons directly to an electrode.
7. a device according to claim 1 that uses photosynthetic molecules to accept electrons directly from an electrode.
8. a device according to claim 2 that uses the photosystem one (PS I) complex to absorb light energy.
9. a device according to claim 3 that uses the PS I complex to donate electrons.
10. a device according to claim 8 that uses biological electron donor molecules to donate electrons to the electron accepting (oxidising) side of the PS I complex.
11. a device according to claim 9 that uses biological electron acceptor molecules to accept electrons from the electron donating (reducing) side of the PS I complex.
12. a device according to claim 8 that uses inorganic electron donor molecules to donate electrons to the electron accepting (oxidising) side of the PS I complex.
13. a device according to claim 9 that uses inorganic electron acceptor molecules to accept electrons from the electron donating (reducing) side of the PS I complex.
14. a device according to claim 1 that uses solid electrodes prepared to permit the transfer of electrons into or out of solution.
15. a device according to claim 2 that uses photosynthetic molecules embedded in a lipid membrane to absorb light energy.
16. a device according to claim 2 that uses photosynthetic molecules embedded in an artificial membrane to absorb light energy.
17. a device according to claim 15 that uses photosynthetic molecules embedded in a lipid membrane, suspended in the pores within some other, solid material.
18. a device according to claim 16 that uses photosynthetic molecules embedded in an artificial membrane, suspended in the pores within some other, solid material.
19. a device according to claim 2 that uses a mixture of photosynthetic molecules obtained from different plant, algal or bacterial species to maximise the absorption of light at a range of different wavelengths.
20. a device according to claim 1 that uses a range of different types of electron transfer molecule in solution.
21. a device according to claims 19 and 20 that contains components in solution to maintain the stability of the photosynthetic and electron transfer molecules.

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Application No: GB0607783.8 **Examiner:** Dr Laura Starrs

Claims searched: 1-21 **Date of search:** 26 October 2007

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-15, 19-21	US2005/0098726 A1 (PEUMANS) - see paragraphs 1, and 27-49
X	1-15, 19-21	WO2006/060017 A1 (PRINCETON) - see p 1 lines 5-13, p4 line 23 - p13 line 2
X	1-7, and 14-18	US2005/0041458 A1 (LOSSAU) - see paragraphs 18-22, and 88-106
X	1-13, and 15-18	Lam K. B. et al, "A bio-solar cell powered by sub-cellular plant photosystems", 17th IEEE International Conference on Micro Electro Mechanical Systems, pp220 223 (2004) Whole document relevant
X	1-15, and 21	Das R et al., "Integration of photosynthetic protein molecular complexes in solid-state electronic devices", Nano Letters, vol. 4, pp1079-1083 (2004) Whole document relevant
X	1, 2, and 9	Lee I et al., "Biomolecular electronic devices with photosystem I reaction centers", 57th Annual Device Research Conference Digest, pp62-63 (1999) Whole document relevant
X	1, and 2	JP04270926 A (STANLEY ELECTRIC) - see PAJ abstract in English and figure 2
A	--	US6231983 B1 (UT-BATTELLE) - whole document relevant
A	--	Cogdell R. J. and Lindsay J. G., "Can photosynthesis provide a 'biological blueprint' for the design of novel solar cells?", Trends in Biotechnology, vol. 16, pp521-527 (1998) Whole document relevant

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.

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Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

H01L

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI, INSPEC, TDB, XPAIP, XPESP, XPI3E, XPIEE, XPIOP, INTERNET

International Classification:

Subclass	Subgroup	Valid From
H01L	0031/04	01/01/2006
H01L	0031/042	01/01/2006
H01L	0051/00	01/01/2006
H01L	0051/42	01/01/2006